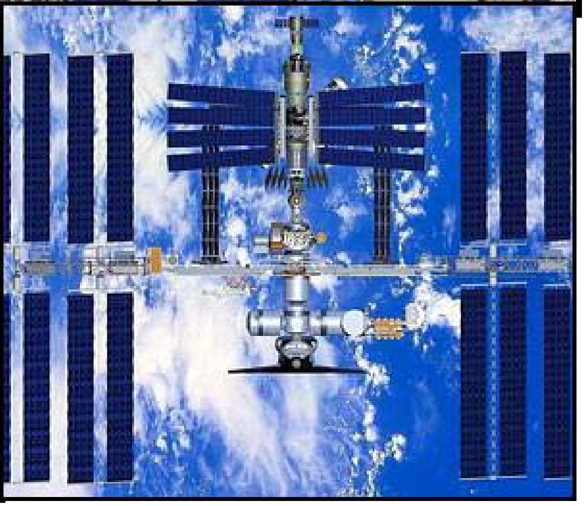
Human Factors and the International Space Station



Thomas Rathjen

Barbara Woolford

Jennifer Novak

Suhakar Rajulu

Mihriban Whitmore

James Maida

Brian Peacock

Human Factors and the International Space Station

NASA Johnson Space Center and the National Space Biomedical Research Institute

Human Factors and Ergonomics Society
Minneapolis, October 2001

The NASA Space Human Factors Community has been applying its knowledge to the design and operation of the International Space Station since its inception.

This panel presentation is aimed at describing some of the activities, success stories and challenges of working in this novel, exciting environment.

Time will be available after the presentations for members of the audience to ask questions and share their own insights into today's situation and tomorrow's opportunities

Thomas Rathjen Comes From Caltech and Wright State University.

He Wears Two Hats:

He Is the NASA Space Human Factors Project Manager and Manager of the Human Factors and Habitability Office at the Johnson Space Center

He Is Also a Pilot and a Rock Star

Space Human Factors Engineering (SHFE) at NASA

- Current Human Space Missions
- Future Human Space Missions
- SHFE Challenges for Current and Future Programs
- Ongoing Program Support
- Opportunities for Advanced Research and Development

Current Human Space Missions

- International Space Station (ISS) Expeditions:
  - Three multinational crew members
  - 3-6 months crew stays
  - Three bus-sized habitable elements, plus an interconnecting node and two airlocks
  - Three phone-booth-sized crew quarters
  - Soyuz “life boat” for emergency return
  - Shuttle/Progress periodic re-supply
  - Typical day:
    - 8.5 hours sleep
    - 7.5 hours exercise/habitability
    - 8 hours station ops and science

Current Human Space Missions

- Space Shuttle flights for ISS assembly/logistics
  - 5-7 multinational crew members
  - 10-12 days
  - Tightly scheduled activities
  - Robotics ops
  - Extravehicular activities
  - Equipment and supplies transfer

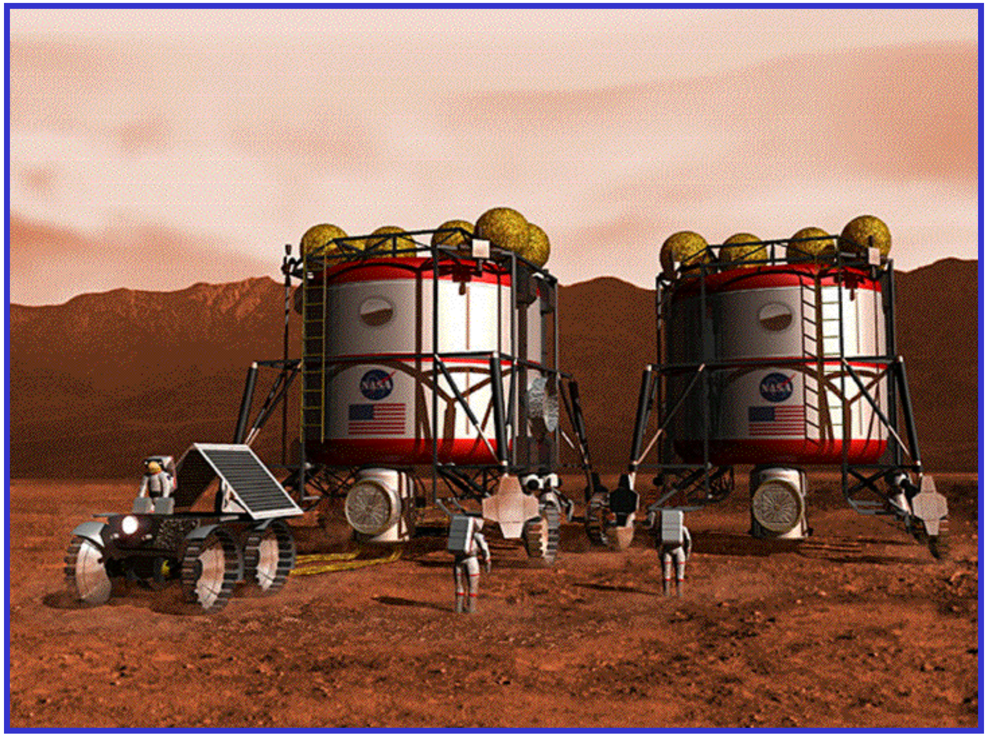
View of the ISS from the Shuttle

Current Human Space Missions

- Shuttle science/research missions
  - Seven (sometime multinational) crew
  - Up to 16 days
  - Single and dual shift ops
- Shuttle missions for satellite (e.g. Hubble) service/repair/deployment
  - Seven (sometime multinational) crew
  - 10-12 days
  - Robotics ops
  - Extravehicular activity

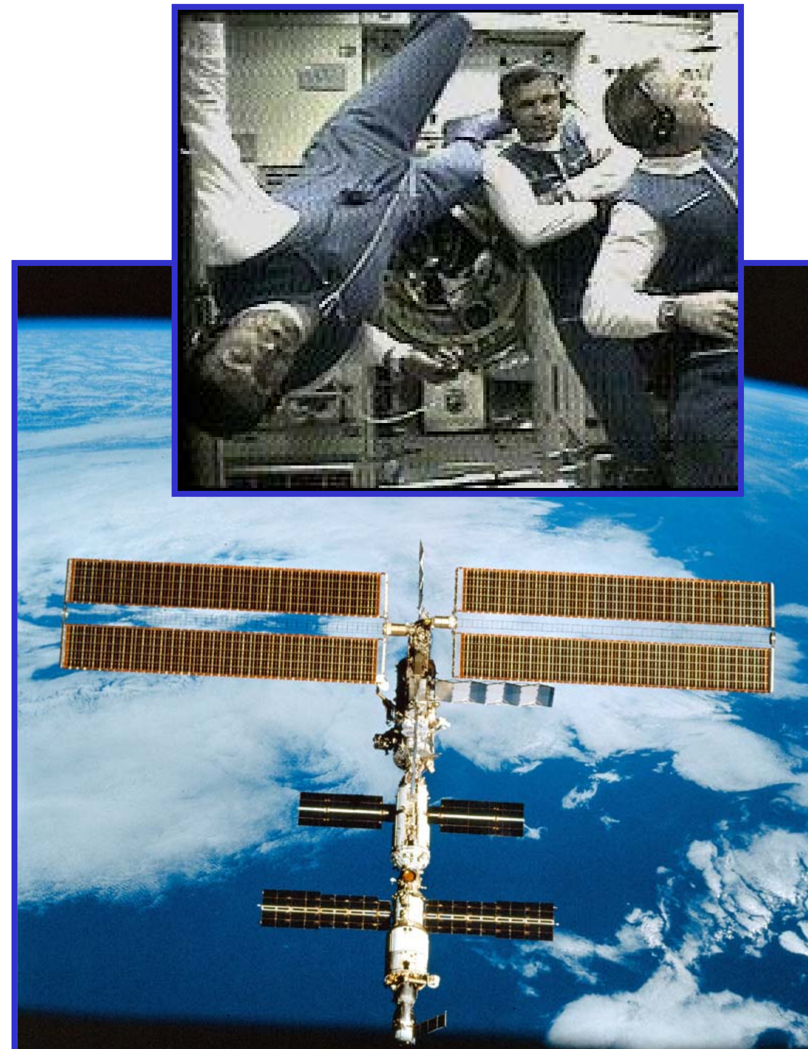
Future Human Space Missions

- Very long duration ISS expeditions?
  - Up to or beyond a year?
  - More crew members?
- Interplanetary?
  - 3 year trips to and from Mars?
- Other?
  - Shuttle replacement vehicle?
  - Lunar missions/station?
  - L-2 station?



Priority SHFE Challenges for Current Programs

- Workload, Crew Activity Scheduling
- Crew Emergency Response
- Human-Computer Interfaces
- Acoustics
- Procedures
- Food Systems (variety, palatability)
- Stowage versus Open Habitable Volume
- Inventory Management
- Modeling of Complex Tasks
- Multi-cultural Considerations

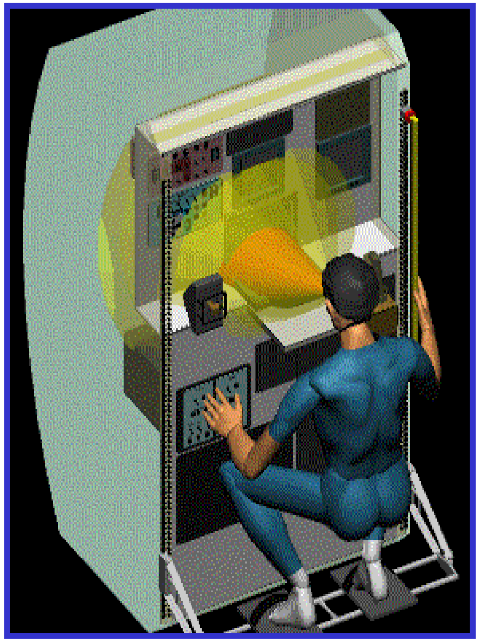


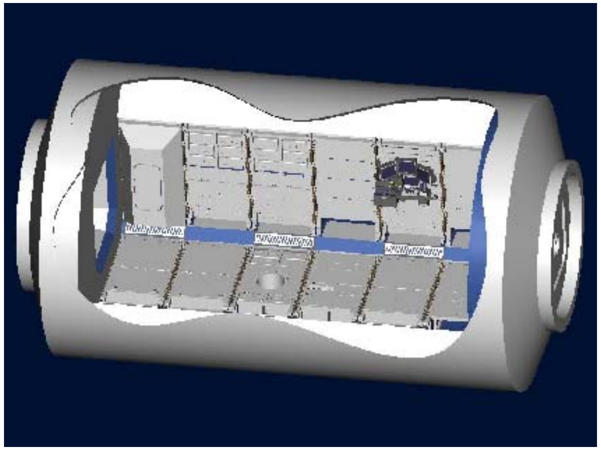
SHFE Challenges for Future Programs

- Extended Duration
  - Isolation
  - Maintain proficiency
- Limited Communications
  - Autonomy
  - Data management
- No Resupply
  - Self-sufficiency
- Multiple g-load phases
  - Zero-g in transit (6 months)
  - Hi-g arrival/landing
  - Partial-g on surface (years)

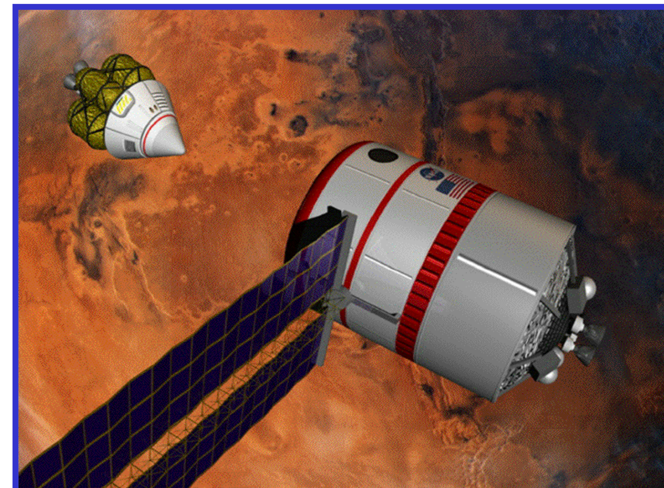
Ongoing Program Support

- Human Factors Modeling, Analysis, Testing
- Human Systems Requirements
- Habitability Systems Design
- Internal Volume Configuration
- Labeling
- Food Systems





Opportunities for Advanced Research

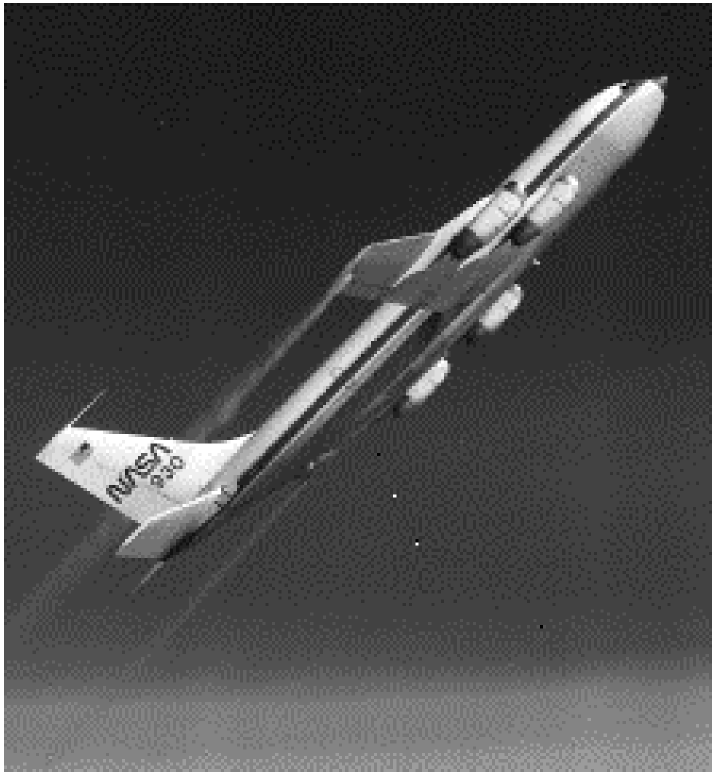


- NASA Research Announcements (NRAs)
  - Basic research
  - Flight and ground-based
- Technology Development Projects
  - Bridge gap between basic research and space flight operations
  - NASA-led, collaboration possible
- Small Business Innovative Research
  - Private sector technological development
- Other
  - Internships, Post-doc programs, Faculty fellowships
  - Collaboration

Dr. Sudhakar Rajulu, who comes from Ohio State University, is our expert on Anthropometry and Biomechanics.

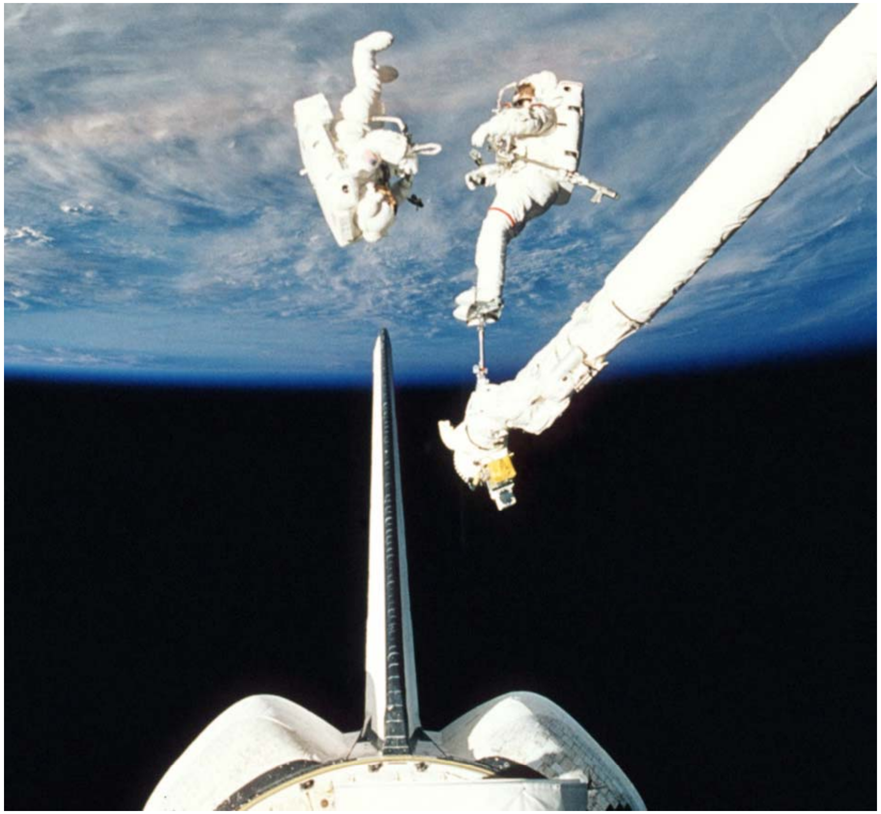
He knows something about the size, shape and strength of our crew members.

He doesn't get sick on the Vomit Comet



Unique Challenges

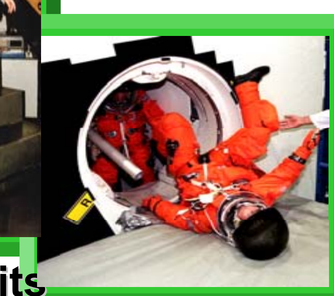
- Short duration effects
- Long duration effects



Anthropometric issues

- Spinal elongation
- Postural change
- Stability
- Reduced range of motion while wearing a suit

Survival Equipment



Sokol suits

Advanced Crew Escape Suit (ACES)

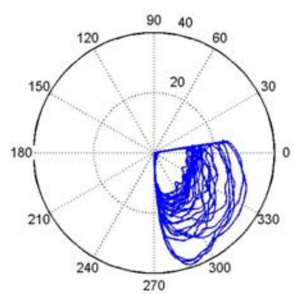
Biomechanics issues

Extra-Vehicular Activity (EVA) Suits

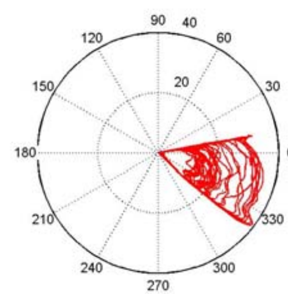
Extra-Vehicular Mobility Unit (EMU)

Orlan EVA Suit

- Reduction in strength (up to 50%) due to wearing a pressurized suit
- Suit fit issues
- Performance



Unsuited



Suited

Constraints

- Astronaut population is small, yet diverse
- All space hardware has to accommodate stringent human factors requirements (5^{th} percentile Japanese female – 95^{th} percentile American male)
- Yet, each mission crewmember must be able to perform well

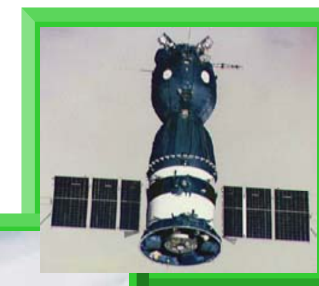
Don/doff study

Problem:

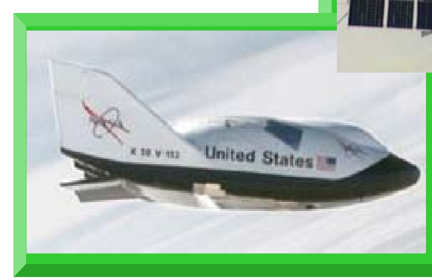
Quantification of crew-induced loads while donning and doffing the suit.

Soyuz seat study.

Emergency Egress Vehicles



Soyuz

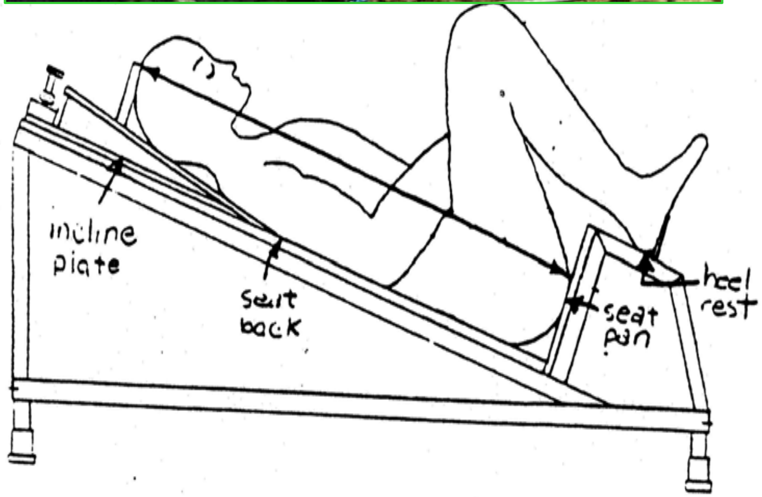


Crew Return Vehicle

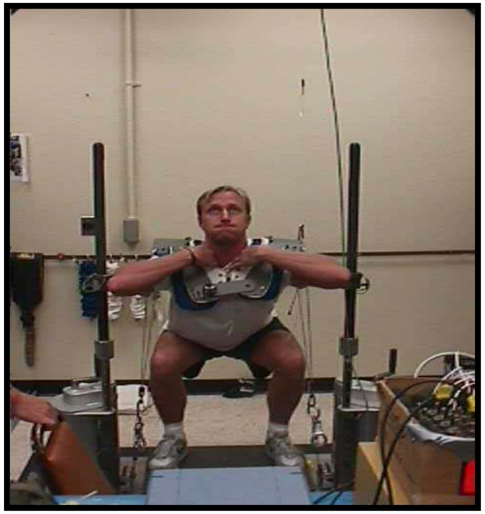
Problem:

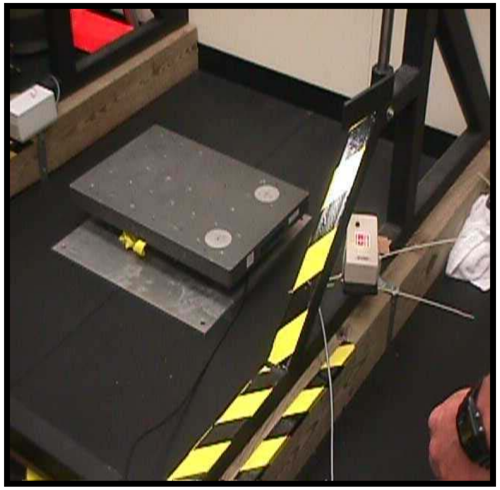
Soyuz seats were not designed to accommodate large U.S. Male crewmembers.

Soyuz seat liner study



Interim resistive exercise device (IRED) study





Problem:

IRED's exercise benefits such as joint loading were needed to be quantified in order to develop a proper exercise protocol

Note: Crewmembers must exercise 1 –2 hours a day to prevent / reduce muscle atrophy, bone loss etc.

Mihriban Whitmore obtained her Ph. D. in Industrial Engineering from Wichita State University.

She Designs Crew Restraints, Mobility Aids and Glove Boxes.

She Is This Year's Recipient of the HFES Alexander J Williams Prize for Her Contributions to ISS and Other Space Vehicle Design

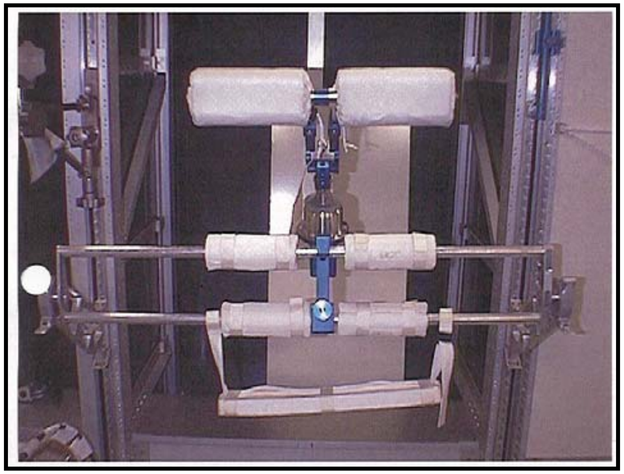
The Silver Snoopy Award from the Astronaut Corps

Mobility Aids and Restraints – Why do we need them in 0-g?

- Translate, move and stow equipment, and provide stability and comfortable posture for precision or high force tasks
- Design challenge: adjustability to accommodate wide range of users versus simple design (ease of use)

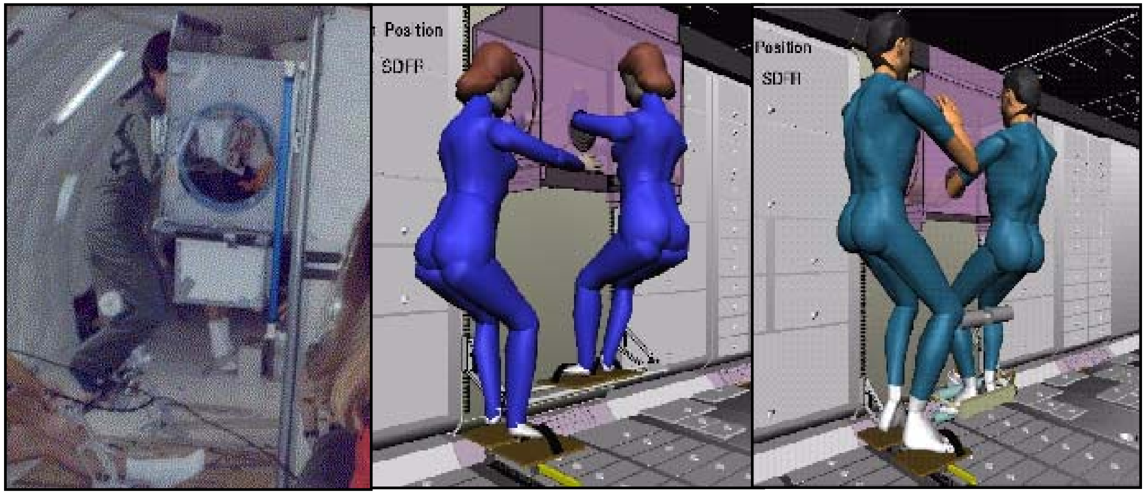
What is up there on ISS?

- –A set of foot restraints
- –Handrails
- –Bungee cords
- –Velcro, duct tape
- –Flexible brackets



Why focus on the glovebox operations?

- –Precision task with repetitive operations
- –Stability and comfortable posture for extended duration
- –Needed for many life sciences and materials experiments



In Flight Data Capture

- Identify the need to capture in-flight data and real-time crew experience on Shuttle, and possibly Mir to determine crew restraint requirements for ISS glovebox operations
- Approach used for ergonomics evaluations of Shuttle and potential glovebox/crew restraints:
  - Video analysis of in-flight or KC-135 working posture
  - Human modeling analysis of flight configuration of glovebox/restraint and crew posture
  - In-flight scale-based questionnaires and postflight debriefs

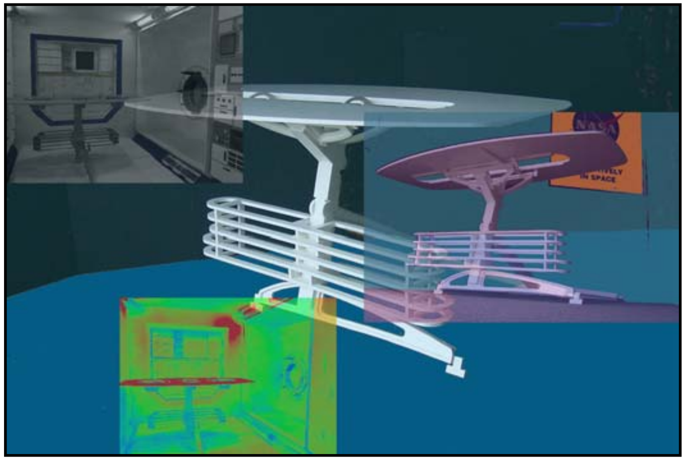
ALBERT and FRED

Analysis and Design

- Significant findings of these ergonomics evaluations:
  - Need for two- (optional three-) point restraining of crew to maintain comfortable, natural posture during the precise/repetitive fine motor tasks – sometimes lasting up to 6 or more hours!
  - Additional guidelines such as simplicity, stability, flexibility, and easy ingress/egress
  - These ergonomics evaluations contributed to new design and promoted awareness of ergonomics in optimum glovebox restraint design
- A two-point restraint used on Shuttle robotic operations was adapted for use at a Shuttle glovebox. At present, the modified version of this design is standard part of the Shuttle robotics workstation for ISS assembly.

Areas where restraint and mobility aids are needed:

- –Crew quarters restraints
- –Wardroom table
- –Galley
- –Portable equipment such as laptops, cameras



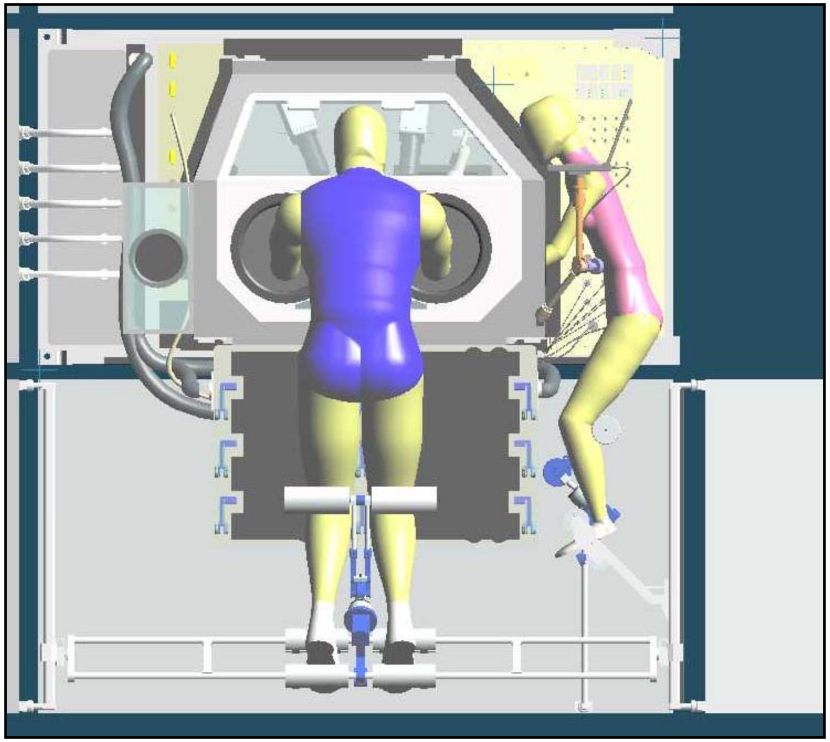
Current work

–Multi-purpose crew restraint concept development for universal use

–Inputs to restraint development for Cupola robotic operations and Life Sciences Glovebox crew restraints

–Adjustability, Accessibility, Mobility, Stability etc.

–Alternative postures



Jim Maida has a Master's degree in Mathematics and Computer Science from the University of Texas at San Antonio.

His expertise is computer-aided human factors analyses.

He is manager of our

Graphics Research and Analysis Facility (GRAF)

and Lighting Environment Test Facility(LETF)

Graphics Research and Analysis Facility (GRAF)

Resolving human factors issues in spacecraft design, analysis and planning using computer aided technology:

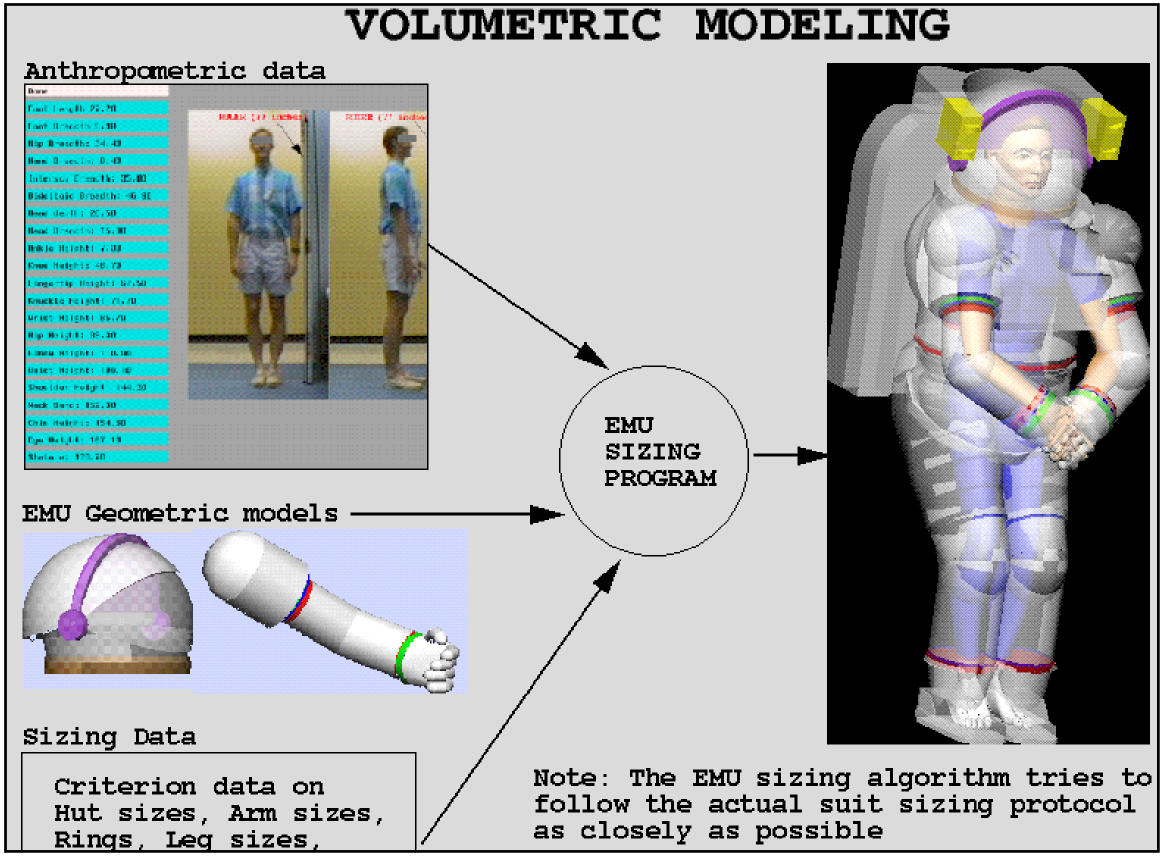
- Digital Human Models
- Lighting Models
- Interior and Volume Control Models

Digital Human Modeling

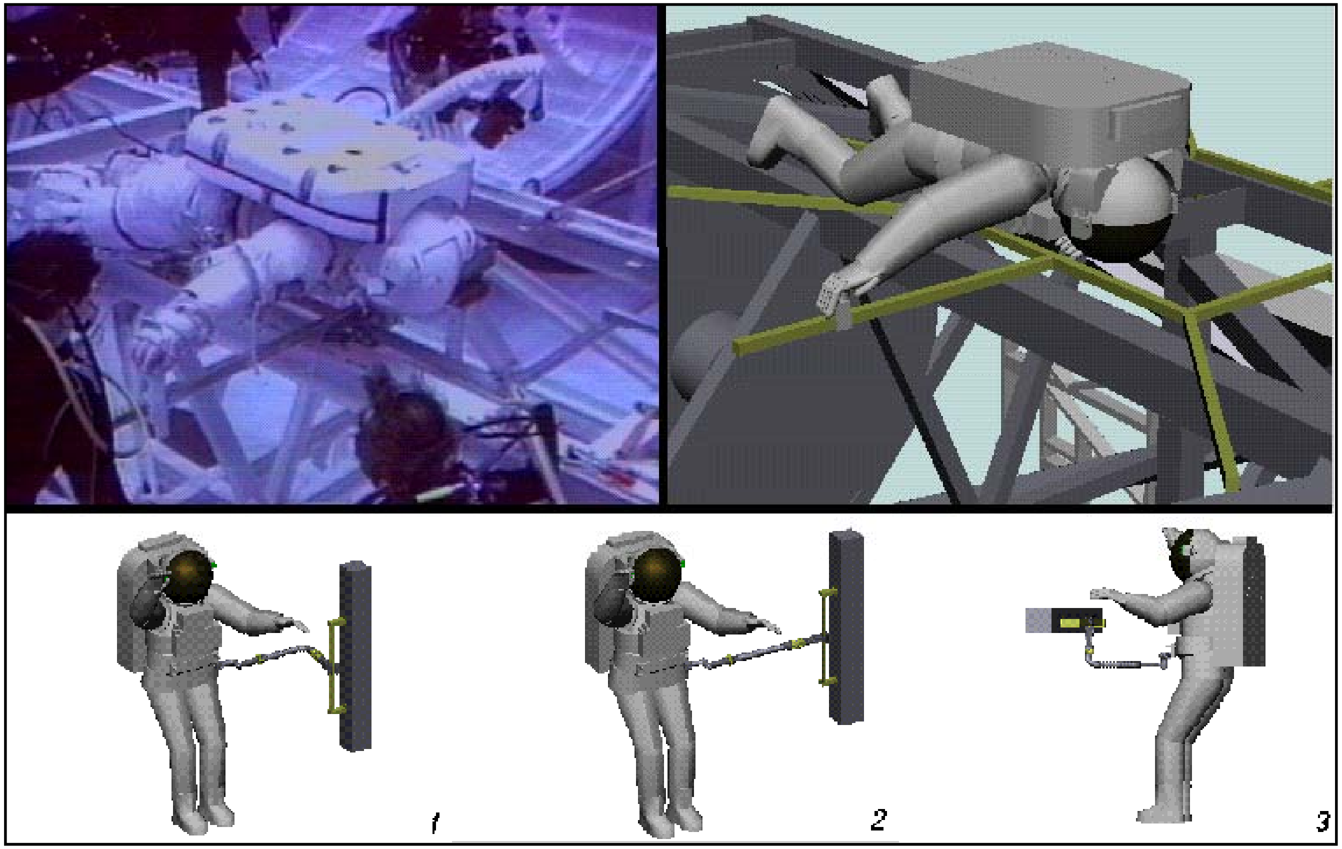
•We currently use an in-house human modeling system.

•It models both suited and unsuited humans.

•Anthropometry is derived from Astronaut Candidate Database.



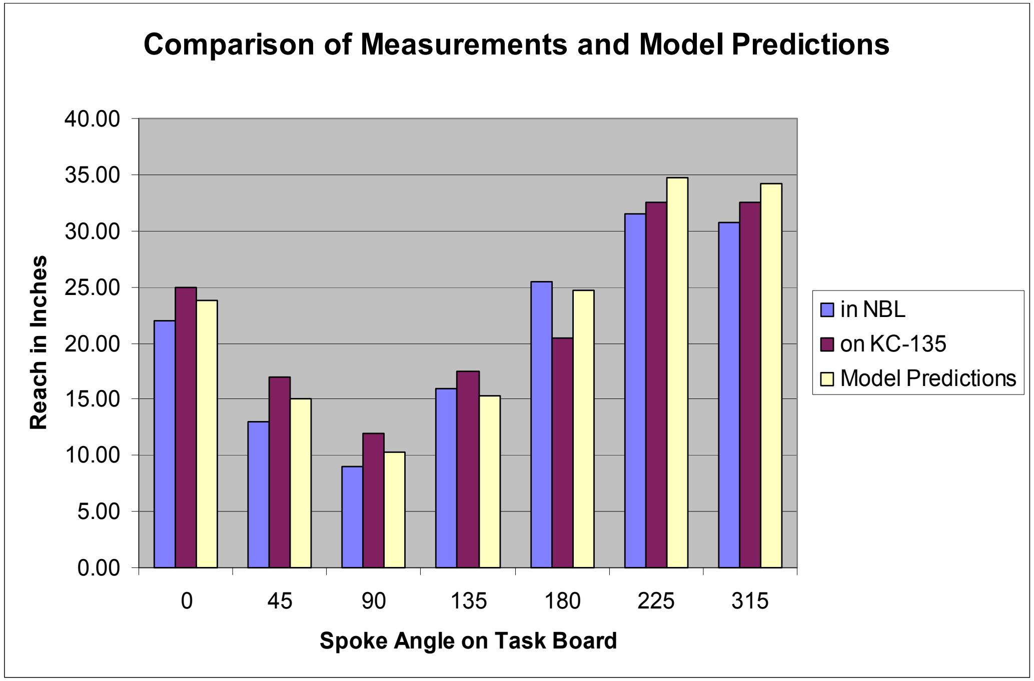
Digital Human modeling is as effective as and less expensive than physical mockups.



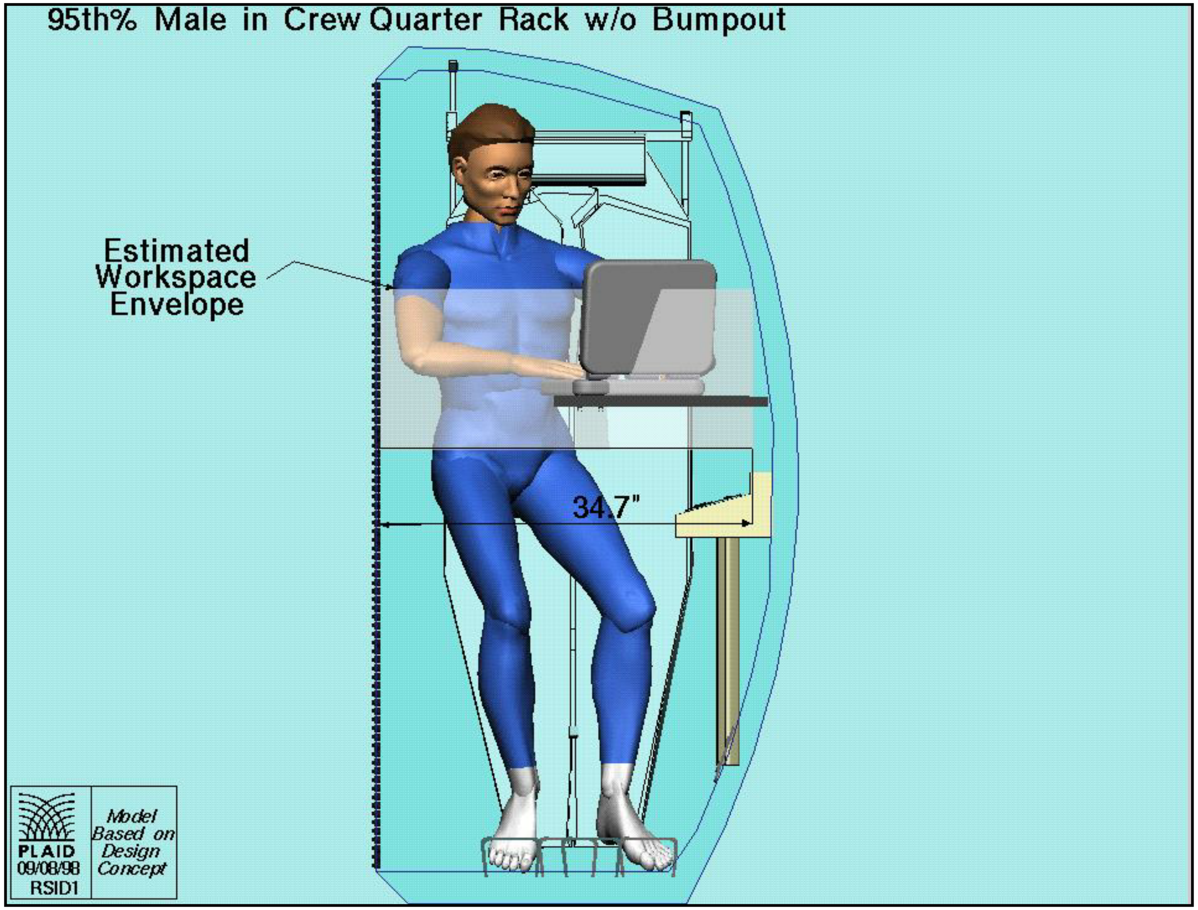
Model Predictions

•Model predictions were as accurate as actual measurements of EMU suited reach limits using body restraint tether in the Neutral Buoyancy Lab (NBL) and on the KC-135 airplane for zero gravity simulation.

•Replacing most of the reach limit measurements with model predictions would reduce time and cost in the NBL and KC-135.



Reach and Fit Analyses



Human Models and Interior Models are combined to provide a volumetric assessment a crew quarter rack.

Lighting Models

•A modified version of Radiance, developed at Lawrence Berkeley Labs, is the primary tool. It has been validated and verified for our applications.

•It has been used to optimize the number of external luminaires required for EVA translation paths.

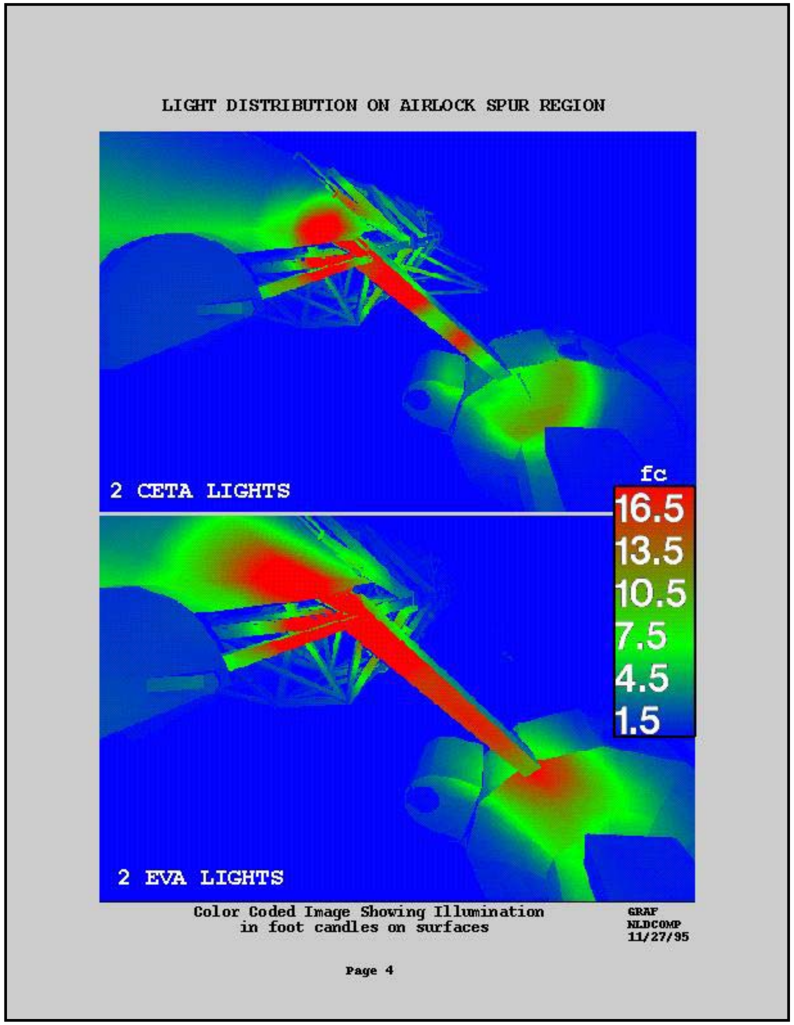
•It is being used for predicting lighting conditions for the Space Vision System (SVS) during berthing operations for Space Station assembly.

•It is being used for designing new interior luminaires.

Exterior Luminaire Evaluation

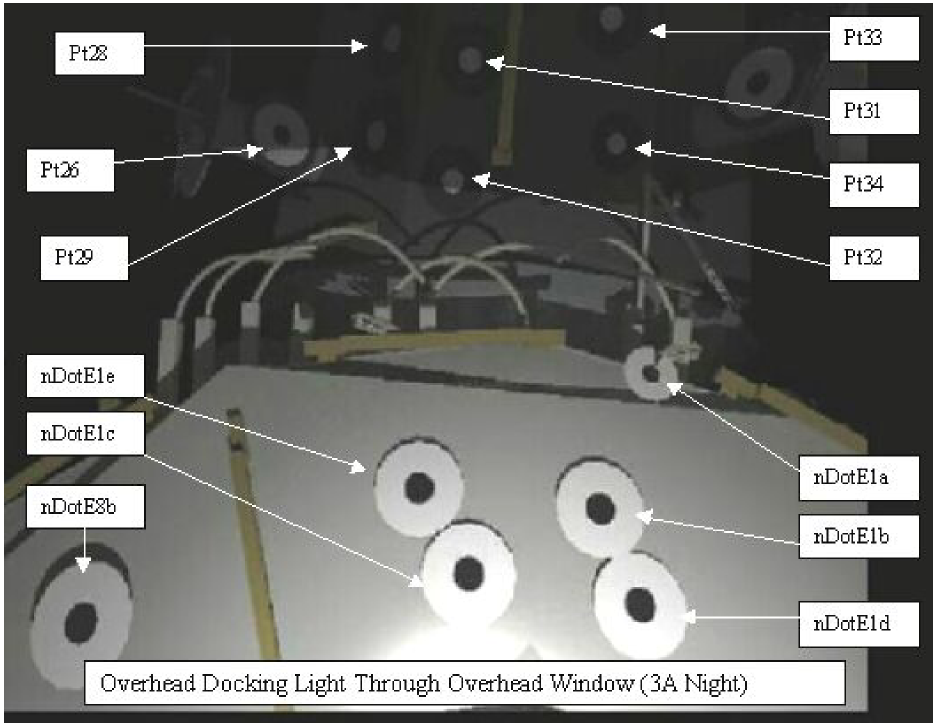
•The goal was to evaluate the location and number of external fixed luminaires or lights required for extra-vehicular activity at key translation paths.

•The evaluation determined that the number of luminaires can be safely reduced by 50%, reducing installation and maintenance costs for the Space Station.



International Space Station Assembly Operations

Predictions of luminance levels for SVS operations, are used to select cameras, select lights, support training, and provide real-time mission support for time-line updates and mission contingencies.



Lighting Environment Test Facility (LETF)

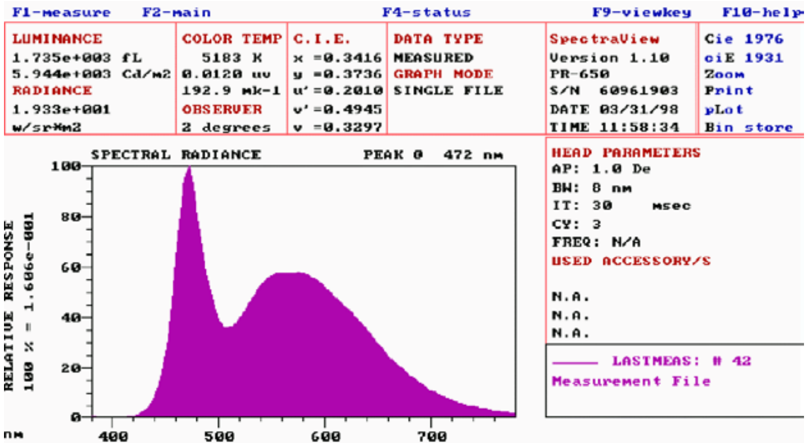
•Investigate and evaluate, both objectively and subjectively, proposed lighting systems for use on space vehicles for both direct and indirect viewing.

•Assess impacts of lighting, artificial and natural, on utilization of crew equipment.

Solid State Task Light

LETF provides evaluation of luminaires (lights) such as, docking lights, portable lights, navigation lights, habitability illumination and task specific luminaires.

Products are measurements and evaluations such as photometric measurements of luminaires, scattering properties of surfaces (BRDF), and color measurements of luminaires and materials.

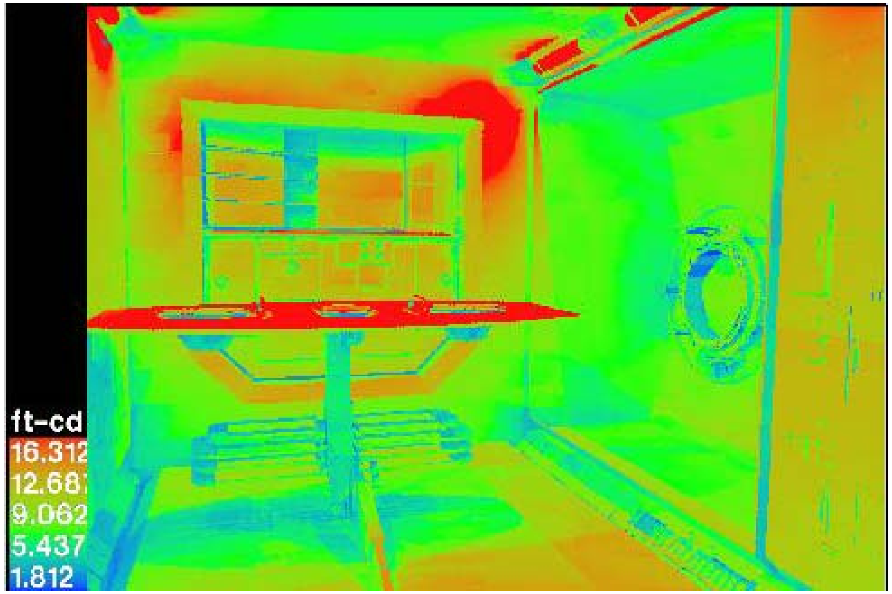


Colorimeter Output for White LED

Evaluation of Solid State Luminaires without diffuser.

SSL are being considered as replacement for fluorescents in ISS.

The design needed to provide equivalent illumination with the same form factor.



Jennifer Novak Received Her Ph.D in Experimental Psychology From Texas Tech.

She Leads the Operational Habitability Team That Contributes Evaluation and Implementation of Human Factors Requirements to the Design of the International Space Station

She is our
#1 Trekkie

Habitability

"...I learned that it is impossible to separate <u>habitability</u> issues from <u>productivity</u> in scientific research. They're one and the same -- from food, toilets, and a good layout of work station space."

David Wolf, <u>Space News</u>, 22, March 16-22, 1998

A day in the life of a space voyager…

- Important, high risk, highly skilled, often long duration, over trained tasks:
  - Extra-vehicular activity
  - Robotics
  - Complex science experiments
- Low risk, routine, non-trained, *high frequency* tasks:
  - Sleeping
  - Bathing, cleaning
  - Dining
  - Resting, relaxing

Space Flight Crew Challenges

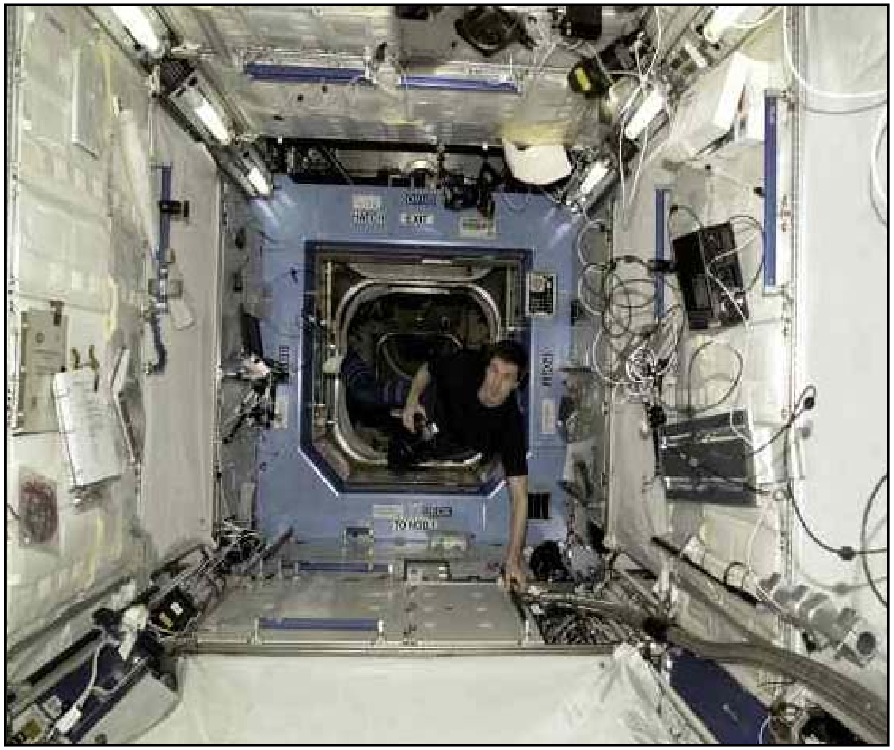
- Visibility
  - Limited ambient lighting (approx. 10 ft. cd.)
- Audibility
  - High ambient noise impacts ability to hear alarms and communication
- Stability and Mobility
  - Staying put without the help from gravity
  - Moving (on purpose) without the help of gravity
  - Congestion

Spatial Orientation: Which way is up?

- Without gravity you can sit on the ceiling
  - Vehicle architecture does not conform to Earth conventions for understanding space (I.e., 2D plans)
- On Earth, one primary cue for spatial orientation is neurovestibular
  - However, neurovestibular system requires gravity
  - Therefore, not much use on a space vehicle
- In Space, the primary valid cue for spatial orientation is visual
  - However, modular design of ISS creates a uniformity in the visual field & undermines available cues

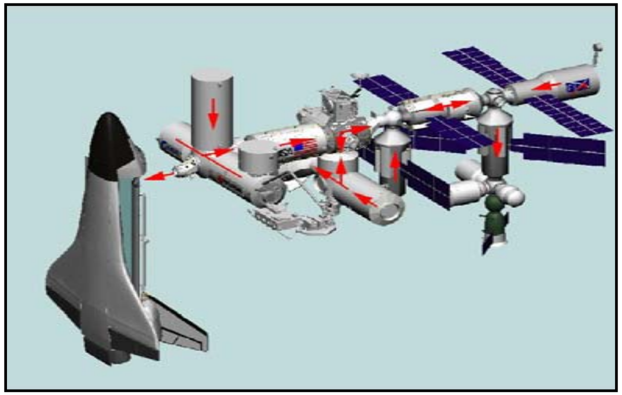
Current ISS Orientation Cues

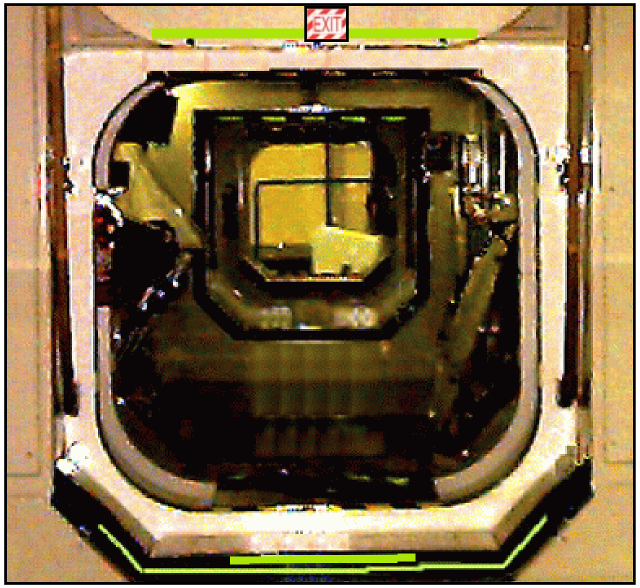
- Local-vertical convention
  - Workstations primarily on “walls”
  - Labels primarily in “vertical” orientation
- Colors
  - One end of module colored, other end white
  - “Ceiling” corners colored, “floor” corners white
- Hatch orientation
  - All modules stow the hatch cover in the “up” position relative to local-vertical
- Labels
  - EXIT labels
  - Direction labels (e.g., “STARBOARD”)



Emergency Egress Challenge

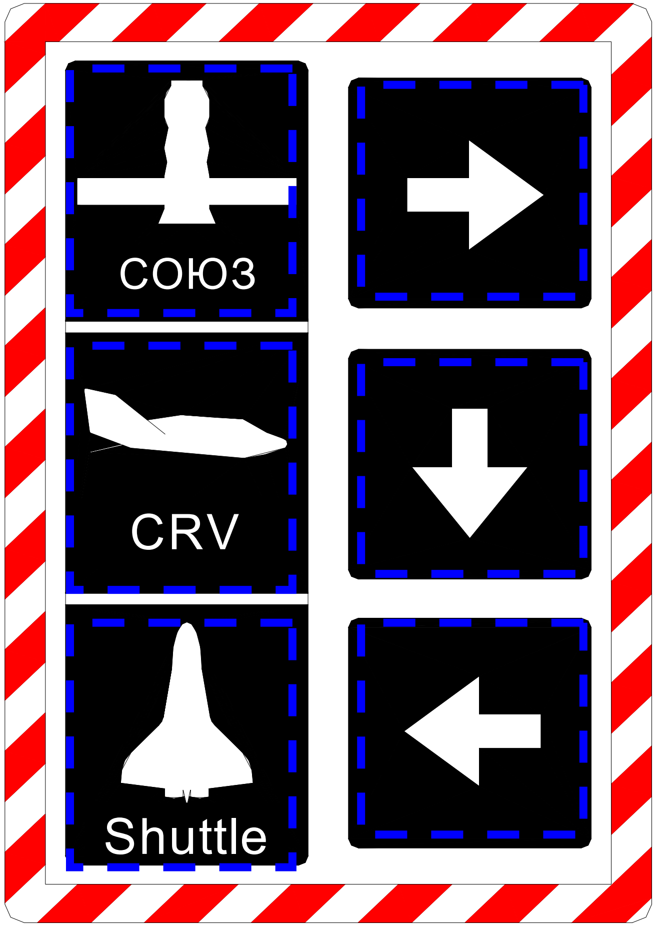
- Worst Case
  - 14 crewmembers going in 3 different directions to 3 different escape vehicles
  - Spatial orientation issues could cause delay or errors and increase egress response time
  - High potential for *reduced visibility* during an emergency egress activity
- ISS provides
  - EXIT signs
  - Emergency egress light strips to indicate hatch
  - Separate distinct egress paths are <u>not</u> identified





Solution: Escape Path Placards

- Multiple Vehicles
  - Icons & arrows to communicate specific escape vehicle direction
- Reconfigure-able
  - Arrows & Icons are separate placards affixed via Velcro on to base placard
  - Allows modification to placard when vehicle or location of vehicle changes (needs procedural step)
- Re-locatable
  - Base placard affixes to wall or other surface via Velcro
- Phosphorescent
  - White portions of placard are fabricated from phosphorescent materials to glow in a reduced-visibility scenario



Barbara Woolford Is the Deputy Manager of the Human Factors Project.

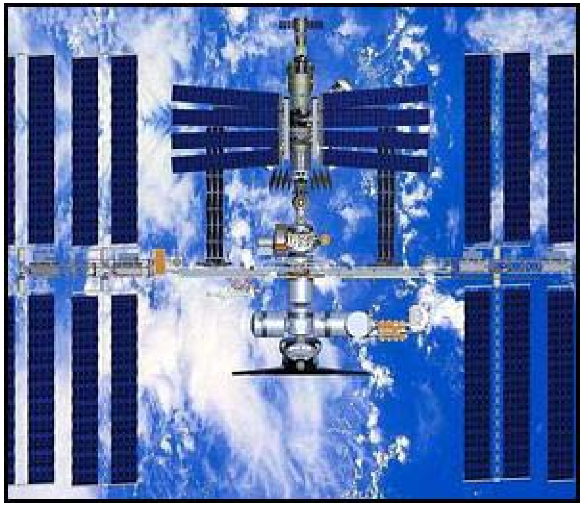
She Knows More About the Space Human Factors World Than Most.

She Also Manages the External Research Program

Talk to Barbara about her dogs

Summary and Future Plans

ISS – the Next 15 Years:



- Make It Better:
  * Operations
  * Crew Equipment
  * Additional Modules
- Study It:
  * Human Factors Research
  * Dedicated Test Objectives

Summary and Future Plans, contd.

Habitability and Human Factors Office will continue to support ISS operations:

Anthropometry and biomechanics measurements and modeling

Lighting measurements and modeling

Operational habitability monitoring and recommendations

Summary and Future Plans, contd.

ISS – A Testbed for Future Space Flight

The Next NASA Program Is Not Determined

-Back to the Moon?

-On to Mars?

-Larger Permanently Occupied Spacecraft?

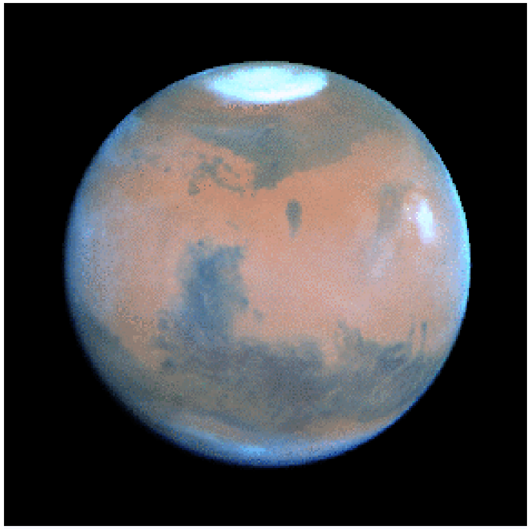


Figure 1. Mars seen from Earth orbit.

We Need to Learn About Living for Very Long Times in 0-g, in a Very Closed Environment, With Increasing Autonomy / Self-sufficiency

Questions and Comments?

We now invite members of the audience to ask questions or offer their insights into the current, mid term and long term research and operational challenges faced by the NASA space human factors engineering community